CollegeBoard AP

Student Performance Q&A:

2009 AP® Physics B Free-Response Questions

The following comments on the 2009 free-response questions for AP® Physics B were written by the Chief Reader, William H. Ingham of James Madison University in Harrisonburg, Virginia. They give an overview of each free-response question and of how students performed on the question, including typical student errors. General comments regarding the skills and content that students frequently have the most problems with are included. Some suggestions for improving student performance in these areas are also provided. Teachers are encouraged to attend a College Board workshop to learn strategies for improving student performance in specific areas.

Question 1

What was the intent of this question?

This was a lab question that tested students' ability to utilize conservation of energy and graphical analysis with a given set of data. The question also asked students to describe a suitable measurement procedure.

How well did students perform on this question?

Almost all students attempted this question, and the mean score was 3.05 out of a possible 15 points. About 6 percent of students earned scores of 12 or higher, while about 70 percent earned scores of 3 or below. This question really discriminated between the top students and everyone else.

What were common student errors or omissions?

Most students did not recognize that the decrease in initial potential energy of the spring (from the pre-launch situation to the peak height) equaled the increase of the gravitational potential energy of the toy. Among students who *did* recognize the energy relationship, a majority (about two-thirds) were unable to use that relationship between variables to determine appropriate quantities to graph in order to determine the spring constant.

Some students had difficulty describing a procedure to make the initial measurement of height. Students often did not distinguish the difference between measurements and calculations. Some students did not recognize the effects of friction and adding extra mass (such as a marker or a laser) to the low-mass toy.

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- Help students recognize conservation-of-energy situations involving springs.
- Give students practice with (1) figuring out relationships between variables beyond simple algebraic manipulation and (2) obtaining information graphically.
- Require students to write more realistic procedures for collecting data during experiments.
- Emphasize lab design and data analysis using both graphical and mathematical methods.

Question 2

What was the intent of this question?

The intent of this question was to determine students' understanding of electrical concepts as well as equilibrium situations. Part (a) asked students to draw the electric field lines in the region of two equally and positively charged spherical objects suspended in equilibrium from strings. Part (b) asked students to derive an algebraic expression for the electric potential halfway between the two charged objects. Part (c) then asked students to draw and label the forces on one of the charged objects (the one on the left). Finally, part (d) asked students to use the conditions of equilibrium to write (but not solve) two equations that could be used to determine both the tension in the string holding the left-most object and the angle that its string made with respect to vertical.

Parts (a) and (b) are typical electrostatics questions. Parts (c) and (d), though, required students to integrate knowledge from two different course topics: Newtonian mechanics and electrostatics. Part (d) especially provided an opportunity for students to show their ability to treat an electric force in combination with other, less abstract forces. Furthermore, because parts (b) through (d) required a response in variables only, this question differentiated between students who thoroughly understand the physical meaning of, say, "electric potential" and those who must rely on merely transferring equations from the equation sheet.

How well did students perform on this question?

Students did not perform well on this question: the mean score was 2.86 out of a possible 10 points. Only about 5 percent of students earned scores of 8 or higher, while about 51 percent earned scores of 2 or below.

What were common student errors or omissions?

In part (a) most students knew that the electric field should be drawn pointing away from both of the positively charged objects (as a positive test charge would be forced). However, many did not know or correctly represent the shape of the field, especially in the region between the two charged spheres.

In part (b) many students seemed not to understand the definition of *derive* on the AP Physics Exams and therefore simply wrote the final algebraic expression or something close to it as the only response to the question. Also, many students confused *electric potential* with *electric potential energy*, *electric field strength*, or *electric force*.

In part (c) many students drew and labeled both the tension vector and its components on the free-body diagram, thus giving the impression that they thought five rather than three forces were acting on the charged object. Many students labeled the forces inappropriately, most frequently mislabeling the electric force acting on the object as E or the gravitational force acting on the object as g.

In part (d) the most common mistakes in writing the equilibrium equations for the left-most charged object had to do with (1) confusing electric force with electric field strength, (2) switching sine and cosine of the angle, (3) not setting the sum of the forces in each direction to zero (indicating an acceleration), and (4) failing to correctly substitute the distance from one charged object to the other in terms of the quantities given.

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- It is very important to thoroughly emphasize the differences among various quantities associated with electrostatics: electric charge, electric potential energy, electric potential, and electric force. Students should be able to describe these quantities, know the standard symbols for each, and be able to solve for or use any of these quantities in problem solving without confusion.

- Teach students to read the directions to the questions carefully, even though they are pressed for time.

- Remind students of the AP Physics Exams' definitions for words like *derive* and the standards for drawing vectors representing forces on an object. To be successful on this particular question, students should have had at least some practice drawing field line diagrams prior to the exam (which, for a majority of students, seemed not to be the case).

Question 3

What was the intent of this question?

This question assessed students' understanding of Ohm's law, Faraday's law, induced magnetic force, the application of Newton's second law, and the influence of a friction force on the given system.

How well did students perform on this question?

Students did not perform well: the mean score was 3.57 out of a possible 15 points. Only about 6 percent of students earned scores of 12 or higher, while about 62 percent earned scores of 3 or below.

What were common student errors or omissions?

Four common errors were noted. The first was students' inability to recognize or correctly apply the concept of Faraday's law. Few students solved part (a) correctly. A typical incorrect response was to use the Ampere's law equation, with the coefficient of friction inserted for μ_0, to solve for the current.

The second common error was confusion over what individual answers actually represented. This error typically occurred in part (a), where students correctly used $B\ell v$ to solve for an emf but labeled it as their answer for current, or in part (c), where students calculated power and indicated that was their answer for energy dissipated.

The third common error was not including one of the two forces in calculating the total force for part (b). The induced magnetic force was typically omitted.

Fourth and finally, students rarely related their answer in part (e) to the numerical answers in parts (c) and (d). Often the numerical answers to parts (c) and (d) were different, but students insisted on stating in part (e) that the energy should be the same due to the principle of conservation of energy.

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- Include electromagnetic induction, an important concept, in the course of study.
- Encourage students to draw a picture with all the forces to help organize their approach to solving a problem (a free-body diagram was not specifically asked for in this question, but drawing one would have helped some students).
- Emphasize the process of examining the solution to a question and describing the physical significance of the answer.

Question 4

What was the intent of this question?

This question assessed students' mastery of thermodynamics, specifically the ideal gas law, internal energy, and the concept of work.

How well did students perform on this question?

Students performed well on this question: the mean score was 5.28 out of a possible 10 points. About 24 percent of students earned scores of 8 or higher, while about 21 percent earned scores of 2 or below.

What were common student errors or omissions?

Many students could not find the correct number of moles due to their inability to convert grams to kilograms. Students also did not understand the difference between work done *on* the gas and work done *by* the gas. For this reason, many did not get the sign correct for the work done. Students did not see the connection between temperature and internal energy, so they tried to use the first law of thermodynamics to solve for internal energy. It is nearly impossible to succeed with this approach because constants that are not on the equation sheet are required to calculate the heat.

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- Invest some time at the beginning of the course on unit conversions, and award significant credit during the year to students who write out full conversions.

- Explain the difference between work done on a gas and work done by a gas, as illustrated in a *PV* diagram.

- Emphasize the relationship between internal energy and temperature for an ideal gas.

Question 5

What was the intent of this question?

This question assessed students' understanding of the concepts of buoyancy and static equilibrium. In part (a) an understanding of Archimedes' principle was needed to explain differences in the buoyant force, and a free-body analysis was required to compare the tensions in the strings for three objects of equal mass hanging in a fluid. In part (b) the buoyant force was to be calculated using the tension and weight of the object. In part (c) this buoyant force was to be used to determine the density of the fluid. Finally, in part (d) students needed to explain changes in tension that would occur if the object was only half submerged.

How well did students perform on this question?

The mean score was 4.84 out of a possible 10 points. About 29 percent of students earned scores of 8 or higher, while about 35 percent earned scores of 2 or below.

What were common student errors or omissions?

Most commonly, students earned points in parts (a) and (d) but did not do well on the calculations. A large percentage of students calculated the weight of the object in part (b) and then called it the buoyant force by (incorrectly) substituting the value of the *object's* density into the buoyant force equation from the formula sheet, $F_B = \rho V g$. These students failed to realize that the density of the *fluid* is needed to calculate the buoyant force on a submerged object.

In part (a) a common error was the use of statements about a reduction of the weight of the object while suspended in a liquid or changes in the gravitational force on the object. In part (b) the most common error was to simply substitute the given object's density and volume into the equation $F_B = \rho V g$ and then call the result the buoyant force. Students did not understand that they must use the density of the displaced fluid in this equation in order to find the buoyant force. Since the fluid's density was not given, an analysis of the object's equilibrium was needed to find the buoyant force.

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- Prepare students for questions involving Archimedes' principle.
- Emphasize that the buoyant force equals the weight of fluid displaced by the object, which depends on the density and volume of displaced fluid.
- Be careful about the use of the term *weight* when discussing the effect of the buoyant force, because students tend to interchange the terms *apparent weight* and *weight*.

Question 6

What was the intent of this question?

This question probed students' comprehension of optical waves and two-source (Young's) interference.

How well did students perform on this question?

This question challenged the majority of students: the mean score was 2.96 out of a possible 10 points. About 11 percent of students earned scores of 8 or higher, while 54 percent earned scores of 2 or below.

What were common student errors or omissions?

In part (a) most students did quite well. Common errors included forgetting to include units in their answer, forgetting to convert the wavelength (given as 550 nm) into meters, neglecting to show all their work, and making simple algebraic errors, such as incorrectly solving the wavelength–frequency–speed equation to obtain $f = \lambda/v$.

In part (b) common errors included failing to recognize that the given equation, $x_m \approx m\lambda L/d$, returns the position of bright fringes, not the separation between two dark fringes. The two distances are numerically equal for $m = 1$; but in order to get full credit, students were required to communicate that they were calculating a fringe separation, not a fringe position. Students also commonly made substitution errors, many times including the slit width w (given in the question statement as 1.2×10^{-6} m) in their calculation, even though it was not needed for any part of the question. Students made frequent substitution and algebraic errors as well.

In part (c) it was very common for students to divide the frequency obtained in part (a) by the index of refraction to get a lower frequency. This failure to recognize that the frequency remains constant also greatly lowered their chances of earning any points in part (d).

In part (d) students who marked "decrease" generally did very well. Their most common error was writing an incomplete explanation of their answer. To earn full credit, students were required to point out that the wavelength decreased in the fluid and that the fringe separation was proportional to the wavelength. Many students left that second part out of their answers, in effect saying, "The distance between the dark fringes decreased because the wavelength decreased, and thus the distance between the dark fringes decreased." It was also very common for students to interpret part (d) in terms of Snell's law, saying that when the index of refraction becomes greater, rays bend toward the normal line and thus the fringes become closer together. However, because the entire apparatus is immersed in water, no refraction occurs, and this explanation is entirely mistaken.

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- Ensure that two-source interference is taught in the sound and waves portion of the course, so that students can perform well on a question like this one, even if they haven't been taught wave optics. (A few students remarked on their exam papers that this was the case.)

- Encourage students to (1) read the question carefully; (2) be sure the equation they are using is appropriate (in this case, using an equation for a fringe separation and not a fringe position, or using an interference equation and not the thin lens equation because it has an f in it); (3) include units in their answer; and (4) show all work, including substitution.

- Remind students to add words or phrases for clarity in their calculations. Many students failed to write an algebraic expression at all, making it difficult for the Exam Readers to determine which equation was being utilized.

- Train students to first write a complete algebraic equation and then to substitute the appropriate values with units.

Question 7

What was the intent of this question?

This question assessed students' knowledge of modern physics, specifically wave-particle duality, the photoelectric effect, and energy-level diagrams. In part (a) students were asked to calculate the kinetic energy of an electron of known de Broglie wavelength. In part (b) they had to calculate the work function of the metal. In part (c) they were asked to identify the electronic transition that created the incident photon.

How well did students perform on this question?

Students did not perform well on this question: the mean score was 2.39 out of a possible 10 points. About 7 percent of students earned scores of 8 or higher, while about 62 percent earned scores of 2 or below.

What were common student errors or omissions?

In part (a) the most common mistake was in calculating the kinetic energy of the electron using Planck's energy equation. Some students used the kinetic energy equation correctly but erroneously substituted the speed of light as the speed of the electron; other students failed to convert the electron wavelength from nanometers to meters.

In part (b) a great majority of students recognized the photoelectric effect process but mistakenly calculated the work function by using the de Broglie wavelength of the electron instead of the incident photon's wavelength.

In part (c) many students interpreted the energy level diagram as a vector diagram and tried to explain the emission of the photon by indicating that their selected transition was in the same "direction" as the example given. Another common mistake was the interpretation of the electronic transition as the magnitude of a given *wavelength*, failing to recognize the inverse proportionality of the wavelength with the change of energy.

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- De-emphasize equation-hunting strategies and instead encourage students to first recognize the relevant concepts before seeking a specific equation.
- Give more emphasis to unit analysis.
- Stress the importance of showing all work and keeping track of units in numerical substitutions.